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SPEECH COMMUNICATION CAPABILITY AND HEARING PROTECTION OF USAF INFLIGHT HEADGEAR DEVICES

AEROSPACE MEDICAL RESEARCH LABORATORY

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AEROSPACE MEDICAL RESEARCH LABORATORY
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FOR THE COMMANDER

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Director
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Air Crew effectiveness depends, to a great extent, on the ability of crew members to maintain adequate voice communication and receive proper hearing protection throughout all phases of the flight mission. Although many factors influence overall speech communication capability, a primary concern is the level of ambient noise associated with the flight environment. To maintain operational effectiveness, the noise in occupied areas of aircraft must be limited to levels where significant degradation of voice communication does not occur. It is essential, therefore, to consider voice communication capability in addition to hearing

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damage risk when defining maximum permissible noise levels for occupied areas of aircraft. In this investigation, both speech intelligibility and hearing protection were determined for various USAF inflight communication headgear devices. Speech intelligibility was measured with talker to listener relationships of quiet to quiet, quiet to noise, noise to quiet and noise to noise. The noise used for both talking and listening was set to 110 dB (re 20μPa) in each octave band from 63 Hz to 2 kHz and 105 dB in the 4 kHz and 8 kHz octave bands. Speech materials were recorded using both boom (kiss-to-talk) and oxygen mask microphones. The results reveal that many noise exposure conditions now specified as satisfactory for military aircraft may be in the range where adequate speech communication cannot be maintained. Although additional research is required, the results of this investigation suggest that current military specifications defining maximum permissible noise level in aircraft should be revised to include consideration for voice communication.

SUMMARY

Air crew effectiveness depends to a great extent, on the ability of crew members to maintain adequate voice communication and receive proper hearing protection throughout all phases of the flight mission. Although many factors influence overall speech communication capability, a primary concern is the level of ambient noise associated with the flight environment. To maintain operational effectiveness, the noise in occupied areas of aircraft must be limited to levels where significant degradation of voice communication does not occur. It is essential, therefore, to consider voice communication capability in addition to hearing damage risk when defining maximum permissible noise levels for occupied areas of aircraft. In this investigation, both speech intelligibility and hearing protection were determined for various USAF inflight communication headgear devices. Speech intelligibility was measured with talker to listener relationships of quiet to quiet, quiet to noise, noise to quiet and noise to noise. The noise used for both talking and listening was set to a level of 110 dB (re 20μPa) in each octave band from 63 to 2 kHz and 105 dB in the 4 and 8 kHz octave bands. Speech materials were recorded using both boom (kiss-to-talk) and oxygen mask microphones. The results reveal that many noise exposure conditions now specified as satisfactory for military aircraft may be in the range where adequate speech communication cannot be maintained. Although additional research is required, the results of this investigation suggest that current military specifications defining maximum permissible noise level in aircraft should be revised to include consideration for voice communication.

PREFACE

This study was accomplished by the Biodynamics and Bionics Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The research was conducted by Henry C. Sommer of the Biological Acoustics Branch, Biodynamics and Bionics Division. The research was accomplished under Project 7231, "Biomechanics of Air Force Operations," Task 723103, "Effect of Operational Noise On Air Force Personnel," and Work Unit 016, "Auditory Responses to Acoustic Energy Experienced in Air Force Activities." Acknowledgement is made to the assistance provided by Sgt E. R. Farina, A1C M. R. Skelton and Mrs. Hazel Watkins of the Biological Acoustics Branch and Mr. L. Keith Kettler of the University of Dayton Research Institute.

INTRODUCTION

Since the early development of the USAF aircraft intercommunication system, one of the greatest single hazards to effective military communications has been the presence of noise. To reduce the noise hazard at both speaker and listener positions, the USAF has developed noise cancelling microphones and noise reducing earcups for use in the inflight communication situation. However, even with the most advanced techniques employed, some portion of the ambient noise environment penetrates the microphone and/or earcups. In the operational situation, where the ambient noise is of sufficient intensity to cause interference with the transmitted or received message, a reduction in intelligibility may result. It is important to define voice communication performance in terms of speech intelligibility as a function of noise environment. Current military specifications[6,7] which establish maximum allowable noise exposures in occupied crew and passenger areas of aircraft have been developed with emphasis on hearing damage risk. Through recent efforts to revise and update these military specifications [6,7] and to establish international standards[2] on maximum permissible sound pressure levels in aircraft, it has become apparent that voice communication performance for operational headgear and microphones is not adequately defined in terms of hearing criteria. The present investigation was conducted to determine (a) hearing protection and (b) speech intellibility for various USAF operational inflight headgear devices under various combinations of noise conditions.

METHOD

SUBJECTS

In this evaluation, subjects performed as (a) talkers or (b) listeners.

(a) Talkers

Two 21 year old male volunteers, selected on the basis of relative linguistic similarly with one another, participated as talkers.

(b) Listeners

Ten male university students ranging in age from 18-22 years, volunteered for participation as listeners in both the speech communication and hearing protection portions of this investigation. As determined by standard audiometric methods, all subjects had normal hearing for test frequencies of 500, 1k, 2k, 3k, 4k and 6k Hertz.

APPARATUS

The apparatus and materials used in this investigation are discussed in terms of (a) test devices (microphones and headset/helmets) (b) talking and listening (c) speech test material and (d) hearing protection.

(a) Test Devices

Figure 1 shows the microphones, headset, and helmets used in this investigation. With the exception of the SPH-4 helmet, all devices shown are standard USAF issue items. In normal use, the M-87 microphone is mounted on a boom and used in conjunction with the SPH-4 helmet and H-157 headset. The M-101 microphone is used in conjunction with oxygen masks with use limited to flight operations associated with high altitude flight. However, for this evaluation, the mask was not connected to an oxygen breathing system.

Figure 1. Headset, Helmets, and Microphones used in this Evaluation

The H-157 headset is used in all aircraft flight operations where oxygen masks are not required and electrically aided voice communication is required. The HGU-26/P [H-154(A)] helmet is the USAF standard (non custom) issue for all fighter pilots. The SPH-4 helmet was developed by the US Army and has been suggested for use by the USAF for helicopter operations.

(b) Talking and Listening

Each talker recorded three lists of 50 words each in a noise and in a quiet environment using each of the two microphones. All recordings were made using a Sony Model 380 tape recorder/reproducer at 7-1/2 inches per second with a microphone input of 4 ohms. The recorded word lists were then randomized and rerecorded in orders that contained speech produced by each talker in noise and in quiet while using each of the M-87 and the M-101 microphones. Tape processing from the original recording was accomplished using an additional Sony Model 380 tape recorder/reproducer. The finalized word lists were presented to each of the ten listeners through an Air Force standard A1C-25 intercommunication set terminated by either (1) an H-157, (2) an HGU-26/P [H-154(A)] or (3) an SPH-4. The recorded speech was so input to the A1C-25 intercommunication system that the characteristics (frequency, level, etc.) were the same as if the speech had been input directly into the intercommunication unit through a microphone. For both talking and listening, the noise was presented as an ambient free field environment with levels set at 105 dB (re 20μPa) for one third octave band center frequencies of 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1.0k, 1.25k, 1.6k, 2.0k, and 2.5k Hertz and at 100 dB for one third octave band center frequencies 4.0k, 5.0k, 6.3k, 8.0k and 10.0k Hertz. These levels produced a noise spectrum that had octave band levels of 110 dB for center frequencies of 125, 250, 500, 1.0k and 2.0k Hertz and 105 dB at 4.0k and 8.0k Hertz. This noise spectrum was produced by one third octave band frequency filtering (Bruel Kjaer 1612/S1A Filter Set and 1612/SP Summing Panel) a white noise (Hewlett Packard Model 8057A noise generator) and amplifying the summed signal via a Stromberg-Carlson 14 kilowatt audio amplifier/loudspeaker system until the desired band levels were obtained.

Both talkers and listeners were positioned in the same portion of the test room. Prior to each talking or listening session, a one third octave band analysis was obtained for purposes of verifying the noise spectrum.

The quiet condition talking and listening sessions were conducted in the same room as that used in the noise sessions. The ambient noise levels for the quiet conditions were below 30 dB in the one third octave band frequency region of 80 to 10.0k Hertz.

(c) Test Material

The speech materials used in this investigation were selected from the standardized Modified Rhyme Test (MRT)[5]. Each test list contains 50 monosyllabic words in the form of consonant-vowel-consonant. The MRT does not require extensive training of subjects and is relatively simple to administer, score, and evaluate. Six lists of 50 words each were used as the basic speech material pool. The 50 words within each of the six basic lists were repeatedly randomized to provide 24 different word lists. Each talker delivered the word in the carrier phrase "Number —, you will mark —— please" separated by a 2 second interval. Prearranged answer sheets corresponding to the various randomized word lists within an order of presentation were provided to the listener. On the answer sheet, six possible words were listed for each stimulus word spoken by the talker, comprising a multiple choice type situation. The listener's task was to strike out the word on the answer sheet that he thought he heard. Since the test form allows for guessing, a certain number of correct responses could be obtained by chance factor alone. To compensate this chance factor, the criterion measure used was percent correct, corrected for guessing. The formula used to calculate the criterion measure* was as follows:

$$\% \text{ correct} = 2 \text{ number correct} \quad \frac{\text{number wrong}}{5}$$

(d) Hearing Protection

Hearing protection was determined for each device. The ten listeners used in the speech intelligibility portion of this investigation also performed the hearing protection evaluation in accordance with the procedure of the American National Standards Institute "Method for the Measurement of Real Ear Attenuation at Threshold[3]." In this method, auditory threshold is measured three repeat times with and without the device in place on the head. The difference between the with and without threshold values is defined as the amount of protection afforded by the device. Hearing protection values are determined for discrete frequencies of 125, 250, 500, 1.0k, 2.0k, 3.0k, 4.0k, 6.0k and 8.0k Hertz.

The instrumentation used to measure hearing protection consisted of: an audio oscillator, an electronic switch, an operator's attenuator (110 dB total range in 1 dB steps), audio amplifier, and a 25 watt loudspeaker. The loudspeaker was positioned 1.3 meters in front of the subject. Subjects found their threshold of hearing by varying their attenuator until the test tone was barely audible.

PROCEDURE

All listeners were tested on four separate days. On the first day, subjects were given a baseline audiogram, instructions and practice on both the hearing protection and speech intelligibility tasks. The second, third and fourth days were used for evaluation of each of the three helmet/headset test devices. The order for evaluation was randomized for each listener. The daily routine for each subject was similar. Each listener, was first given an audiogram, then fitted with the test device to insure the best possible fit and earcup seal. After the necessary adjustments were made to the test device, listeners participated in the hearing protection evaluation. After completion of the hearing protection evaluation, subjects were then given a fifteen minute rest period during which they were escorted to the speech intelligibility test area. Listeners then donned their headgear test item and were seated in the test room. The recorded speech test material was then played to the listeners. Listening levels were fixed at the mid gain position of the AIC-25 intercommunication unit. The input speech was monitored to insure a constant speech level input. At the conclusion of the speech intelligibility evaluation, subjects were removed from the test area, given a post exposure audiogram, and dismissed for the day. For each subject all testing was completed in a two week period.

RESULTS

HEARING PROTECTION

Table 1 presents the mean hearing protection and standard deviation values for each of the helmet/headset devices. In general, for both the low (125 and 250 Hertz) and mid (500 to 4.0k Hertz) frequency regions, the SPH-4 provides slightly more hearing protection than either of the other devices. In the higher frequency region (6k and 8k Hertz) the HGU-26/P [H-154(A)] provides slightly better hearing protection.

Table 2 presents the dB(A) reduction values for each device as a function of various dB(C) minus dB(A) classes. These dB(A) reduction values were determined for the mean ($\overline{X}$) and mean minus one standard deviation ($\overline{X} - 1\sigma$) values calculated from Table 1. The mean ($\overline{X}$) applies to those values expected for 50% of the population, while the mean minus one standard deviation ($\overline{X} - 1\sigma$) applies to an 84% population coverage. The methods used to calculate these dB(A) reduction values have been described in detail elsewhere[4]. Basically, the "A" weighted overall sound pressure level (dBA) is a single number representation used to describe a noise. The "A" weighted level is such that considerable weighting is provided for in the low frequencies. The "C" weighted overall sound pressure level (dBC) provides another single number representation of the same noise, however, little weighting is applied. Because

TABLE 1

HEARING PROTECTION VALUES

DEVICE		*FREQUENCY (Hz)* 125	250	500	1000	2000	3000	4000	6000	8000
SPH-4	Mean	15	13	29	27	31	39	50	34	30
	St. Dev.	(3)	(3)	(5)	(3)	(5)	(5)	(6)	(7)	(9)
HGU-26/ H-154(A)	Mean	11	11	21	21	34	41	46	38	33
	St. Dev.	(4)	(4)	(8)	(4)	(5)	(6)	(7)	(6)	(8)
H-157	Mean	9	14	22	33	32	32	39	29	22
	St. Dev.	(4)	(3)	(5)	(6)	(6)	(6)	(7)	(7)	(6)

TABLE 2

SINGLE NUMBER ATTENUATION FACTORS (dBA)

Device		*"C-A" VALUES* -2 to 0	1 to 3	4 to 7	8 to 12	13 or >13
	$\bar{X}$	28	26	23	19	14
SPH-4	$\bar{X} - 1\sigma$	24	22	19	16	12
HGU-26/P	$\bar{X}$	25	22	20	16	11
[H-154(A)]	$\bar{X} - 1\sigma$	19	17	15	11	7
H-157	$\bar{X}$	27	24	21	17	12
	$\bar{X} - 1\sigma$	22	20	17	14	9

of the differences in weighting characteriscics, the dBC minus dBA ("C-A") value indicates the relative contribution of the low frequency energy to the overall sound level reading. A "C-A" value that is negative, zero, or a small positive number indicates that the low frequencies contribute little to the overall sound level. A large "C-A" value indicates that the low frequency energy influences the overall sound level. Since most ear protectors provide little hearing protection in the low frequency region (125-250 Hertz), defining hearing protection as a single dBA reduction value that covers all noise spectra would be impossible. For this reason, the data of Table 2 are provided. For example, a fixed wing jet aircraft spectrum would be such that a low "C-A" value would be obtained and therefore the helmet or headset would provide maximum reduction of the A-weighted overall sound level. A helicopter noise spectra has a considerable amount of low frequency energy and consequently a large "C-A" value. As observed from Table 2, the larger the "C-A" value, the less effective the hearing protection device because of general poor low frequency performance.

SPEECH COMMUNICATION

Analyses of variance were calculated on the data obtained from each talker to listener relationship (quiet to quiet, quiet to noise, noise to quiet, and noise to noise). Significant effects were found only for microphones in talker to listener conditions of quiet to quiet and noise to quiet. Figure 2 shows the main effects for microphones for all talker to listener relationships. For talking from quiet to quiet, the mask microphone (M-101) provides a statistically significant improvement over the boom microphone (M-87) while for talking from noise to quiet, the opposite is true. To better understand this effect, Figure 3 presents the speech intelligibility scores for each of the talker to listener relationships for each helmet/headset device for both microphones. From this figure, it can be observed that for the quiet to quiet condition, higher scores were obtained for all devices when speech was recorded using the mask microphone, while the reverse was found in talker to listener relationships of noise to quiet. This effect was not observed for the same talking conditions when listening in noise. Although a statistically significant difference was observed for microphones, the actual percent difference in intelligiblity scores (2 to 5%) is not expected to be of practical consequence. Figure 4 presents the intelligibility scores for each headset/helmet device as a function of each talker to listener relationship used in this investigation. As expected, talking from a noise environment to a noise environment (pilot to co-pilot) produces scores considerably below those for the quiet to quiet condition. In general, the condition of talking from quiet to noise (tower to pilot) provides slightly better intelligibility than from noise to quiet (pilot to tower). This indicates that noise entering the microphone has slightly more effect on speech reception than the effect caused by the noise at the earphone. However, additional investigations are required to verify the significance of this finding.

DISCUSSION

Of particular interest in this investigation was the fact that no significant differences were observed among any of the listening devices in any of the talker to listener relationships. Consequently, the type of device worn by the listener appears to make little difference to speech reception capability in the noise conditions examined in this study. However, the significant effect found for microphones in talker to listener relationships of quiet to quiet and quiet to noise were quite surprising. When the talker and listener are both in quiet, the mask microphone (M-101) provides for greater speech intelligibility over the boom microphone (M-87) while the reverse is true with a talker to listener relationship of noise to quiet. Therefore, the type microphone used in an aircraft may be an important consideration prior to the determination of maximum allowable noise levels. It has generally been assumed that in any given noise environment, the mask (M-101) microphone used with the MBU 5/P oxygen mask would yield better intelligibility than the M-87 boom microphone. This assumption is based on the fact that additional noise reduction is afforded the M-101 microphone through the rubber mask associated with the MBU 5/P mask resulting in a better speech to noise ratio at the input.

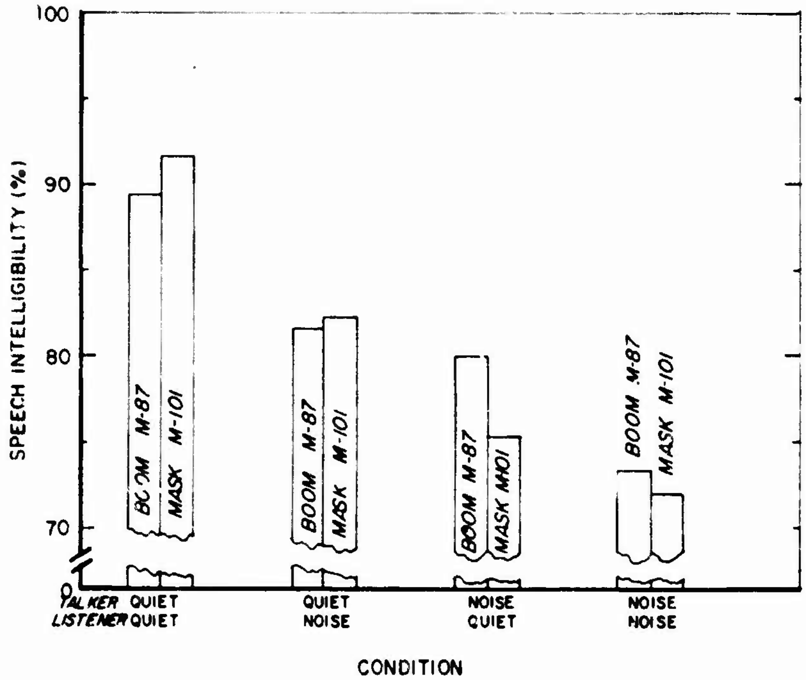

Figure 2. Main Effect for Microphones as a Function of Talker and Listener Conditions

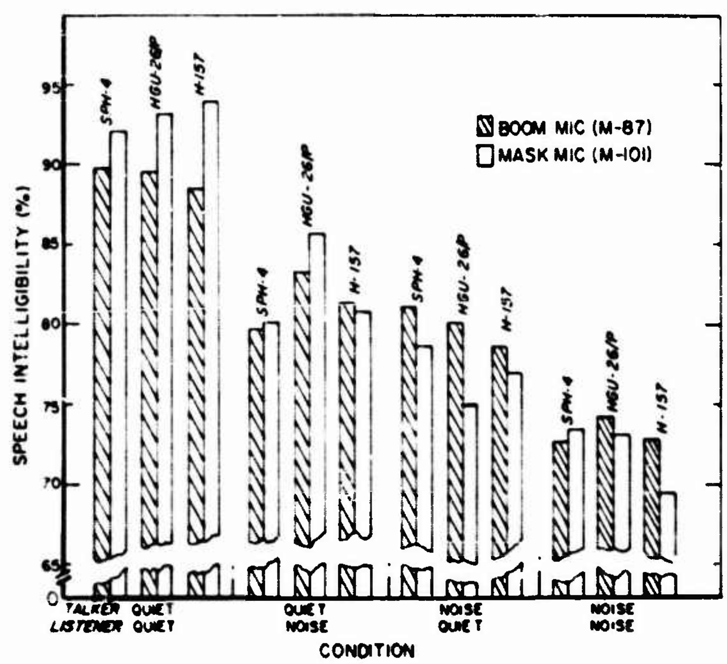

Figure 3. Speech Intelligibility as Function of Listening Devices, Microphones, and Talker to Listener Conditions

The hearing protection afforded by the SPH-4 helmet is 1 to 2 dB better than that provided by the H-157 headset and from 3 to 5 dBA better than that for the HGU-26/P [H-154(A)]. In terms of hearing damage risk exposure criteria[4], Air Force Regulation (AFR) 161-35 requires a decrease of 4 dBA for every doubling of exposure duration. Therefore approximately twice the allowable exposure duration can be tolerated if the SPH-4 helmet is worn in place of the HGU-26/P [H-154(A)]. However, this slight increase in hearing protection of the SPH-4 over the HGU-26/P [H-154(A)] does not appear to influence speech reception capability when listening in noise. In fact, inspection of figure 1 reveals that speech intelligibility for the quiet to noise and noise to noise condition is slightly better when using the HGU-26/P [H-154(A)] over any of the devices tested.

In Figure 5 the noise spectrum and level used in this investigation are compared to those levels and spectra provided in MIL-S-8806B for the protected ear. For the condition where both talker and listener are in noise (pilot to co-pilot) the speech intelligibility for the Modified Rhyme Test (MRT) was in the lower 70 percent category. This is at or near the minimum acceptable performance allowable for aircraft intercommunication systems. It should be noted however, that the gain of the AIC-25 intercommunication set was set to mid position for this investigation. Increasing the gain to maximum, an increase in speech level of 16 dB, would increase speech reception capability. However, it must be remembered that data collection in this investigation was conducted under ideal conditions (e.g. maximum fit and seal of the earcups associated with the helmet and headset devices). Therefore, it is questionable whether in an actual flight situation the speech reception is any better even if the gain level is set to maximum.

Additional investigations are required to determine the effects of operational flight (jet, prop and helicopter) noise on speech communication capability when listening at different gain setting levels. However, consideration should be given to reducing the levels permissible for the 15 minute and 30 minute durations now specified in MIL-S-8806B. Particularly since these levels and durations are specified for take off (Curve E) and climb (Curve F) where intelligible voice communication is most essential.

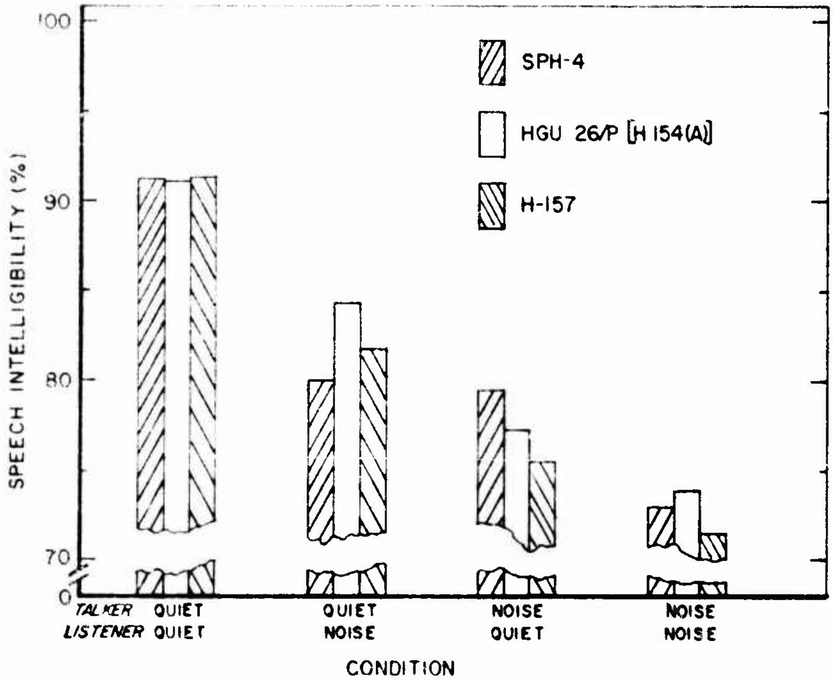

Figure 4. Speech Intelligibility as a Function of Listening Devices and Various Talker to Listener Conditions

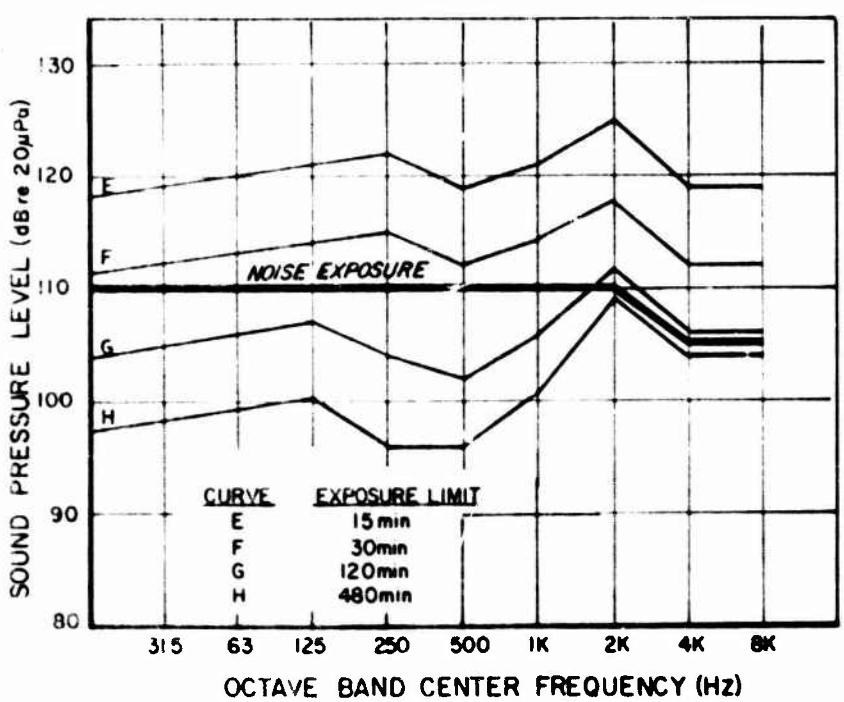

Figure 5. Octave Band Noise Exposure Levels Used in This Investigation Versus Criterion Ambient Noise Exposure Levels as Defined in MIL-S-8806B For Crew Members

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